ENERSEARCH

Energy Technology Development

Ontario Ministry of Energy

Vincent G. Kerrio
Minister

FIELD TESTING AND MONITORING OF TWO HIGH EFFICIENCY CONDENSING GAS BOILERS INSTALLED IN A HIGHRISE BUILDING

PROJECT NUMBER 6266/620142

Report prepared for the

ONTARIO MINISTRY OF ENERGY

by

AQEEL ZAIDI, M.Sc
CHARLES RHODES, Ph.D
EDMOND SCICLUNA, B.A.Sc
DAVID RYGIER

ADMIC CONTROLS

Participating Agencies:

ONTARIO MINISTRY OF ENERGY

THE CONSUMERS GAS COMPANY LIMITED

Funding for this project was provided by the Ontario Ministry of Energy under the EnerSearch Program.

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ACKNOWLEDGEMENTS

We wish to thank Mr. Thomas Markowitz of the Ontario Ministry of Energy, and Mr. Martin McCall of the Consumers' Gas for their assistance, support and contributions to this study.

We would also like to thank Dr. Orland Schauss, Mr. John Overall and Mr. Z. Dzialoszynski (Steve Dee) at the Canadian Gas Research Institute for their technical support.

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ABSTRACT

This report presents the design, installation, operation and thermal performance results of two ADMIC high efficiency condensing gas boilers. The ADMIC boiler design was a further refinement to the condensing boiler developed by the Canadian Gas Research Institute. The ADMIC boilers were retrofitted to an existing hydronic heating plant located in the basement boiler room of a high-rise apartment building in Metro Toronto.

Key innovative features of the ADMIC boiler include:

1. reduced physical size for easy installation;
2. high operating pressure (1379 kPa/200 psig) suitable for basement installations;
3. low exhaust temperatures allowing use of plastic vent pipes; and
4. no restriction on boiler location or stack installation due to power venting.

The monitoring results show that the ADMIC high efficiency boilers were operating at a seasonal thermal efficiency of 86% whereas the two conventional boilers were operating at efficiencies of 68% and 64%. The total energy savings at this site are estimated at 4032 GJ per annum by comparing the ADMIC boilers' efficiency with the conventional boilers' efficiencies. Based on a natural gas rate of $4.74 per GJ, these energy savings translate into cost savings of $19,112.00 per annum. The economic analysis shows a simple payback period of 2.25 years for the extra cost of an ADMIC high efficiency boiler as compared to a conventional boiler.

The application of these condensing boilers for direct domestic hot water heating should be further investigated since these boilers produce efficiencies in excess of 90% at low inlet water temperatures.

EXECUTIVE SUMMARY

This report details the demonstration of ADMIC high efficiency gas fired condensing boilers in a retrofit application to a multi-residential high-rise apartment building. The report outlines the installation, commissioning, operation and thermal performance results of two ADMIC high efficiency condensing boilers in the basement boiler room of a 150 suite high-rise apartment building in Metro Toronto. These boilers were added to supplement the space and domestic hot water heating for the building. Each boiler has an input capacity of 1,000,000 Btu per hour. These boilers are designed for continuous duty base load applications, and are best applied as lead boilers in a building.

The monitoring results on the thermal performance of the two ADMIC high efficiency condensing boilers, when compared with the monitoring results of two existing conventional boilers (one Ray Husky forced draft fire tube boiler and one Raypak atmospheric water tube boiler), indicate that the ADMIC condensing boilers are more efficient than the two conventional boilers.

The ADMIC boiler design was a further refinement to the design of the condensing boiler developed and tested by the Canadian Gas Research Institute (CGRI). Some of the changes made by ADMIC to the CGRI boiler design include:

1. the overall length and diameter of the boiler was reduced to allow entry through most boiler room doors; the 1,000,000 Btu per hour input capacity was retained;

2. the pressure vessel was redesigned for 1379 kPa (200 psig) for basement mechanical room installation in high-rise buildings;

3. the original epoxy-coated iron tubes were replaced by stainless steel tubes to reduce corrosion and hence extend the tube life;

4. the controls were modified for soft-start operation in order to eliminate possible "popping" effects on start up and shut down of boilers; and

5. the exhaust vent previously constructed from stainless steel was replaced by high temperature Fiberglass Reinforced Polyester exhaust vents with stainless steel vent terminals.

The ADMIC boilers commenced ongoing operation on January 23, 1987. The test period described herein was completed on June 1, 1987. Each boiler registered approximately 1635 operating hours during the test period and showed continuous and reliable operation.

Additional observations included the following:

1. The monitoring results showed that the two ADMIC high efficiency condensing boilers were operating at a seasonal thermal efficiency of 86% whereas the two conventional boilers, Ray Husky and Raypak, were operating at thermal efficiencies of 64% and 68%, respectively. A comparison between these efficiencies shows that the ADMIC condensing boilers were operating 34.4% more efficient than the Ray Husky boiler and 26.5% more efficient than the Raypak boiler.

2. The annual energy savings produced by the ADMIC high efficiency condensing boilers, as compared to the conventional boilers, are estimated at 4032 GJ per annum. Of the 4032 GJ, the space heating energy savings were estimated at 3498 GJ per annum by comparing the ADMIC boiler efficiency of 86% with the Ray Husky boiler efficiency of 64%. The domestic hot water energy savings of 534 GJ are estimated by comparing the ADMIC boiler efficiency of 86% with the Raypak boiler efficiency of 68%.

3. Based on a natural gas rate of $4.74 per GJ, the total energy saving of 4032 GJ per annum will yield a cost savings of $19,112.00 per annum.

4. In this application, a simple payback period of 2.25 years can be realized for the ADMIC high efficiency condensing boiler assuming that the installation costs for a high efficiency boiler and a conventional boiler are approximately the same. The differences in the purchase price would be recovered from the energy savings produced by the high efficiency boiler.

5. Application of the ADMIC condensing boiler for direct hot water heating should be investigated since the boiler produces efficiencies in excess of 90% in the condensing mode.

Present concerns regarding the condensing boiler in general are:

i) the condensate pH value measured at 3.6 suggests that the condensate be diluted or chemically treated prior to disposal;

ii) the outside vent stack terminals should be located away from the building to avoid any possible complaints related to the exhaust plume.

The high efficiency for the ADMIC condensing boilers is achieved by:

1. recovering the latent heat from the flue gases by condensing the water vapour present in the combustion products;

2. increasing the sensible heat recovery due to enhancement of the heat transfer by the use of specially designed flue baffles;

3. reducing stand-by losses by using spark ignition instead of a standing pilot;

4. optimizing combustion through use of a specially designed power gas burner; and

5. a mechnical configuration that has very low shell thermal losses.

1. INTRODUCTION

ADMIC designed, manufactured and installed two one million Btu per hour high efficiency gas fired condensing boilers in a high-rise apartment building with assistance from the Ontario Ministry of Energy. The two ADMIC boilers were installed in the basement boiler room of a 150 suite high-rise apartment building in Metro Toronto. These boilers combined with the existing heating system provide space and domestic hot water heating for the building.

The commercial condensing boiler developed and tested by the Canadian Gas Research Institute (CGRI) formed the basis of the design of the present boilers. Certain design modifications were made to the CGRI boiler, and some new concepts were implemented in the manufacture of and installation of the ADMIC condensing boilers which are further discussed in this report.

The main objectives of this study were:

1. To monitor the operation and thermal performance of the two high efficiency condensing boilers in a retrofit application.

2. To monitor the thermal efficiency of the existing Ray Husky firetube and Raypak atmospheric boilers.

3. To evaluate the energy savings resulting from the condensing boilers by comparing their performance with the existing conventional boilers.

4. To assess the reliable operation of the new boiler technology.

ADMIC installed a sophisticated monitoring and data acquisition system to evaluate the thermal performance of all four boilers with assistance from Consumers' Gas.

2. RATIONALE

Conventional boilers used in high-rise apartment buildings have consistently demonstrated seasonal efficiencies in the 55% - 70% range.

The ADMIC high efficiency condensing gas boilers have demonstrated an efficiency of 86% which translates into high energy savings. In addition, these boilers reduce the emission of nitrogen oxides by 30%, as compared to conventional boilers with similar heat outputs.

3. BACKGROUND

Approximately five years ago, the Canadian Gas Association engaged the Canadian Gas Research Institute to develop a high efficiency high reliability gate station heater. CGRI built and installed a one million Btu per hour boiler in a gate station in Metro Toronto.

Three years ago, the Canadian Gas Research Institute built and tested a one million Btu per hour commercial boiler for a building space heating application in a one storey building in Whitby, Ontario.

In 1986 ADMIC acquired the rights to this boiler technology from CGRI and the Ministry of Energy. ADMIC modified the design for application to multi-residential high-rise buildings.

The following limitations are found in other high efficiency condensing boilers presently available and approved in Canada.

i) The capacity of 150,000 Btu/hr is too small for a high-rise apartment building.

ii) The venting limitations and the low pressure ratings prevent their installation in basements of high-rise buildings.

ADMIC successfully resolved these limitations, and in 1986 built two boilers and installed them in the basement boiler room of a high-rise residential apartment building in Metro Toronto. The operation of these condensing boilers has been continuous and reliable since January, 1987.

4. SYSTEM DESCRIPTION

4.1 BOILER DESIGN AND CONSTRUCTION

The ADMIC boiler design was based upon the CGRI boiler developed and tested in 1984/85 heating season as described in the CGRI report entitled "High Efficiency Commercial Gas Boiler Evaluation". ADMIC incorporated the following design modifications:

i) The overall length of the boiler was reduced from 244 cm (96") to 208 cm (82") and the diameter of the boiler was reduced from 91.5 cm (36") to 86.4 cm (34") to allow the pressure vessel entry through most boiler room doors in retrofit applications. The total heat transfer area of the tube bundle was maintained by increasing the number of tubes from 26 to 32.

ii) The pressure vessel was redesigned to operate at a higher pressure of 1379 kPa (200 psig) as compared with the original pressure of 207 kPa (30 psig), to make the ADMIC boiler suitable for highrise buildings. The present pressure vessel is certified by the Ministry of Consumer and Commercial Relations to operate at 1103 kPa (160 psig).

iii) The original epoxy-coated steel tubes were replaced by acid resistant stainless steel tubes to reduce the possibility of corrosion and hence, to extend the life of the boiler tubes.

iv) The controls were modified for soft-start operation.

In addition to the above modifications, a computer control system replaced the indoor/outdoor controller. Also, fiberglass reinforced polyester was used for venting the boilers.

4.2 BOILER INSTALLATION

4.2.1 Site Preparation

The site was prepared to accommodate the two new ADMIC boilers by cutting and removing an existing damaged 6 million Btu/hr firetube boiler. Blanking plates were installed where the damaged boiler previously was connected to return and supply headers. The existing defective gate valves were replaced by butterfly valves. The gas line was capped and later connected to the new ADMIC boilers.

4.2.2 Moving Pressure Vessels Inside the Boiler Room

Once the site was prepared, the pressure vessels were moved to site. A crane was used to lower the pressure vessels down the stairwell and a block and tackle were mounted inside the boiler room to pull the boilers through the door. It is anticipated that future basement retrofit applications would require similar arrangements to move the pressure vessels into boiler rooms.

4.2.3 Boiler Assembly

The line diagram for an ADMIC boiler at the Royal York Road site is shown in Figure 1. The pressure vessels were mounted in cradles sloped towards the collector hood to ensure proper condensate drainage. The flue tube baffles were installed and the boiler assembly was completed by installing the burner and gas train, controls, electrical control panel and collector hood. The boiler and collector hood were insulated with two inch thick fiberglass insulation with canvass jacketing.

The ADMIC boiler employs a specially designed power gas burner which includes the following features:

i) A radial flame provides uniform heat distribution over the tube sheet.

ii) A high turn down ratio (1,000,000 Btu/hr to 360,000 Btu/hr) and modulating capability allow continuous boiler operation, resulting in high boiler thermal performance.

4.2.4 Boiler Plumbing

Both boilers were piped together using 3" line in a reverse-return configuration, to allow equal pressure drop across each boiler, as shown in Figure 2 (Section 4.4). A balancing valve was installed in the common 6" bypass line to achieve the desired flow through the boilers. The common return and supply for these boilers were connected to the existing headers through a valving arrangement, which allows connection of these boilers to the existing plant in various configurations.

Gas connections were provided to each boiler through a set of pressure regulators and shut-off valves.

The power to each boiler was provided through a 120V, 15 amp circuit breaker.

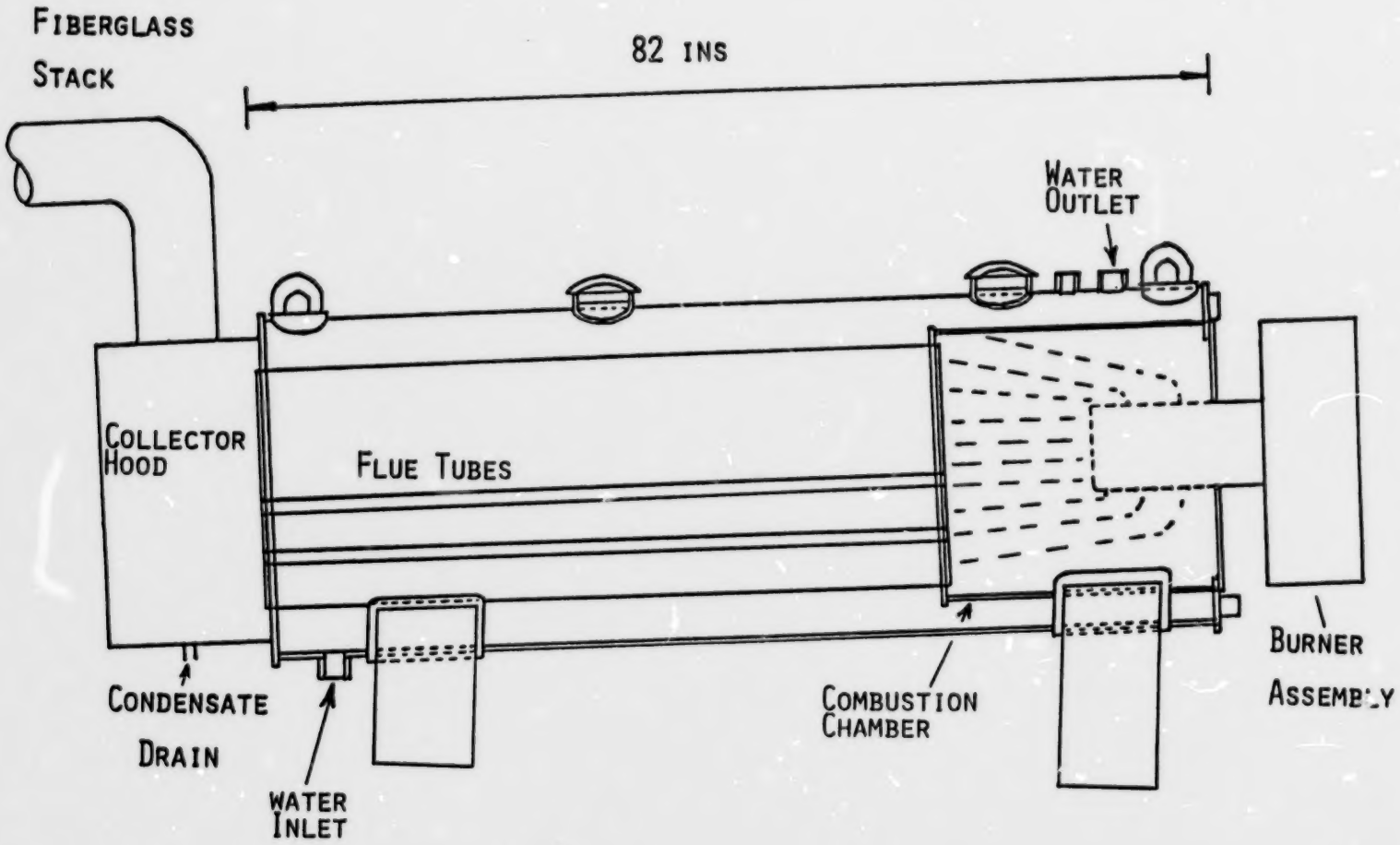

FIGURE 1 ADMIC BOILER AT ROYAL YORK ROAD

4.2.5 Venting

Eight inch diameter fiberglass piping, rated at 300 F and 264 psi, was installed to vent the exhaust from each boiler. These vent pipes run close to the ceiling across the room, through the existing concrete wall and then run 45 feet outside underground and 8 feet upwards above the ground, where stainless steel vent terminals are provided as rain caps. The venting is sloped slightly towards the boilers, to ensure proper drainage of condensate.

Fiberglass pipe was used for venting instead of stainless steel because the fiberglass:

- does not corrode,
- has a lower thermal conductivity,
- has improved flow, due to smooth surface,
- is easier to handle and install, and
- is suitable for direct burial.

Originally the outside vent stacks were located 25 feet away from the building. The stack piping was extended by another 20 feet away from the building to avoid possible complaints. This suggests that in future installations careful consideration should be given to the location of vent stacks and dilution of the exhaust plume.

4.2.6 Site Approvals

Site approvals were obtained from various regulatory authorities before commissioning the boilers. The Canadian Gas Association approved the installation on December 24, 1986 and Ontario Hydro approval was issued on January 14, 1987.

4.3 INSTALLATION AND OPERATION OF 3-WAY MIXING VALVE

A six inch 3-way mixing valve was installed in the building space heating loop, as shown in Figure 2 (Section 4.4), to control the building space heating supply water temperature and to maintain a constant water temperature in the Ray Husky boiler. In the midwinter heating mode, the Ray Husky boiler discharge temperature is approximately 180 F which is high for usual building space heating requirements. The valve operation is controlled by the ADMIC microprocessor using a direct digital control algorithm.

4.4 DESCRIPTION OF SPACE AND DOMESTIC HOT WATER HEATING SYSTEM

The schematic for the building space and domestic hot water heating system is shown in Figure 2. The specifications for boilers are summarized in Table 1.

Depending upon the season, boilers operate in the following modes to provide space heating for the building, the garage and domestic hot water heating.

i) Midwinter mode

ii) Early and late Winter mode

iii) Spring and Fall mode

iv) Summer mode

Each boiler's ON/OFF status and the valving arrangement associated with each mode are summarized in Table 2.

In the Midwinter mode, the building and garage space heating loads are met by the two ADMIC boilers and the Ray Husky boiler. The two ADMIC boilers run all the time as base load and the Ray Husky boiler turns on only when the space heating load exceeds the ADMIC boilers output capacity of 1.8 million Btu per hour. The domestic hot water is heated by the Raypak boiler.

In the early and late Winter mode, the space heating is solely provided by the two ADMIC boilers and the domestic hot water is supplied by the Raypak boiler, and may be supplemented by the ADMIC boilers when capacity is available.

In the Spring and Fall, the two ADMIC boilers provide the entire space and domestic hot water heating load.

In the Summer, the domestic hot water load is supplied by one ADMIC boiler.

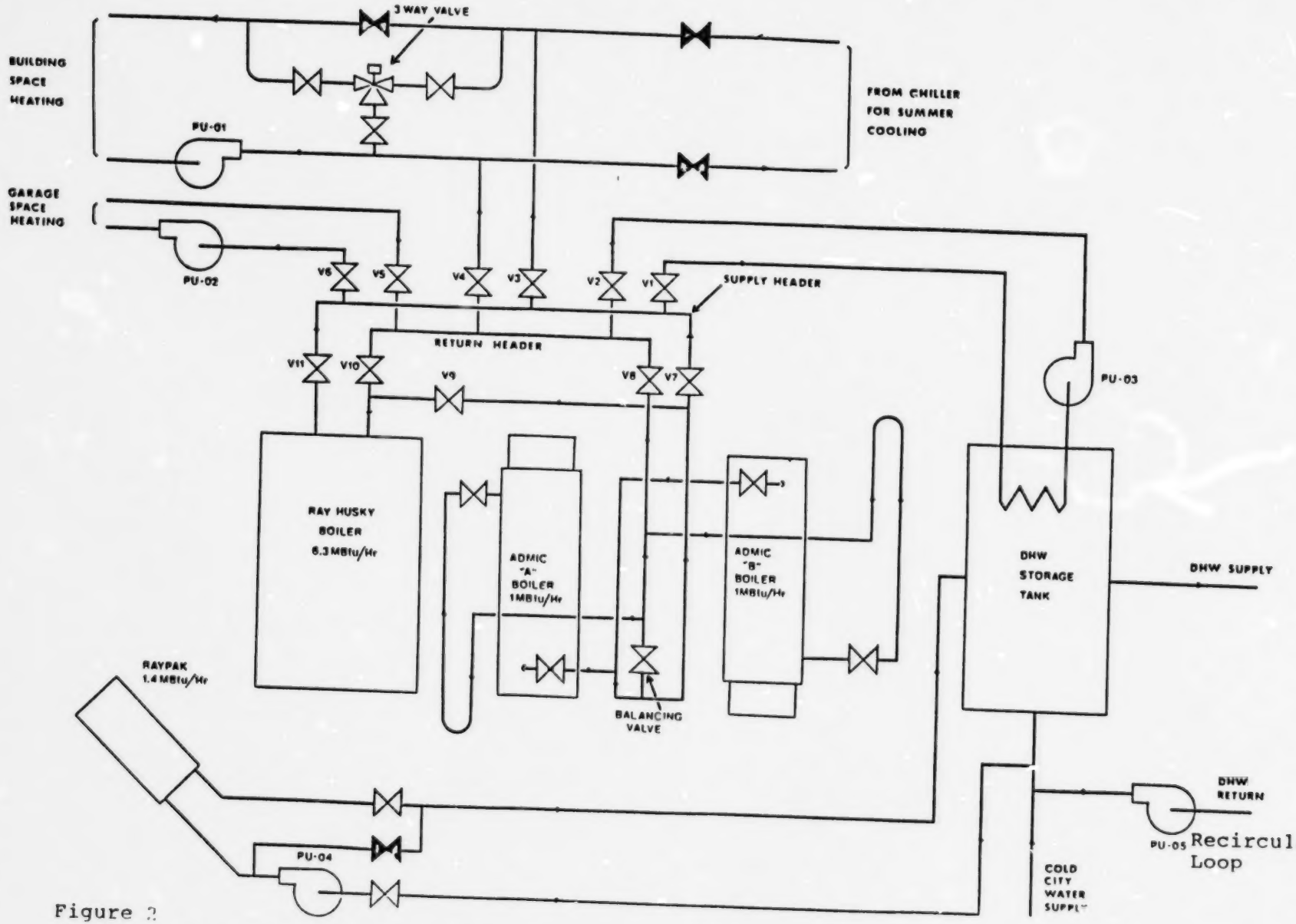

Figure 2

FLOW SCHEMATIC FOR 1407 ROYAL YORK SPACE AND DHW HEATING SYSTEM

TABLE 1

BOILER SPECIFICATION

	ADMIC	RAY HUSKY	RAYPAK
Max Input (Btu/hr)	1,000,000	6,300,000	1,467,000
Min Input (Btu/hr)	360,000	4,200,000	293,400
Output (% or Btu/hr)	84% - 93%	N/A	1,173,600
Fuel Type	Natural Gas	Natural Gas/oil	Natural Gas
Max. Manifold Pressure	7" W.C	5.2" W.C	4" W.C
Fuel Supply Pressure	14" W.C	14" W.C	7" W.C
Ignition	Spark	Spark	Standing Pilot
Draft	Forced Draft	Forced Draft	Natural Draft
Combustion	Power Combustion	Power Combustion	Atmospheric Combustion

TABLE 2

BOILER STATUS AND VALVE POSITIONS FOR EACH OPERATING MODE

Mode	Boiler Status			Valve Positions	
	ADMIC A and B	Ray Husky	Raypak	Open	Closed
1. Midwinter	ON	ON	ON	V3, V4, V5, V6, V8, V9, V11	V1, V2, V7, V10
2. Early and Late winter	ON	OFF	ON	V3, V4, V5, V6, V7, V8	V1, V2, V9, V10, V11
3. Spring and Fall	ON	OFF	OFF	V1, V2, V3, V4, V5, V6, V7, V8	V9, V10, V11
4. Summer	ON	OFF	OFF	V1, V2, V7, V8	V3, V4, V5, V6, V9, V10 V11

5. DESCRIPTION OF THE MONITORING AND DATA ACQUISITION SYSTEMS

5.1 MONITORING INSTRUMENTATION

The monitoring equipment and sensor locations are shown on Figure 3. The equipment make, model numbers, conversion factors, ranges and accuracies are summarized in Table 3.

The vortex flowmeters were installed by providing adequate straight entrance and exit lengths as specified by the manufacturer, except for the 6" diameter flowmeter. It was not possible to provide this entrance length due to space limitations. In this case the entrance and exit lengths were both reduced to approximately half their specified values.

The temperature sensors were installed inside thermo-wells for accurate fluid temperature measurements.

Precision gas regulators were installed upstream of each gas meter to minimize the pressure fluctuations in the gas supply.

A precise barometric pressure transducer was installed to record the atmospheric pressure. The atmospheric pressure data was required for accurate measurement of gas flows.

5.2 TEMPERATURE SENSOR CALIBRATION

The temperature sensors were calibrated in a temperature bath against a mercury thermometer to within a $\pm$0.1 C accuracy at the calibration point. Each heat metering temperature sensor pair was further digitally corrected after installation to track precisely its mate over the operating range. The calibration procedure is described in detail in Appendix A.

5.3 DATA ACQUISITION SYSTEM

The data acquisition system is microprocessor based. All sensors shown on Figure 3 are interfaced to the microprocessor. This microprocessor scans all sensors and, in addition to computing engineering calculations, performs the following operations:

- controls operation of ADMIC, Ray Husky and Raypak boilers;
- controls 3-way valve operation; and
- provides information on the status of various devices.

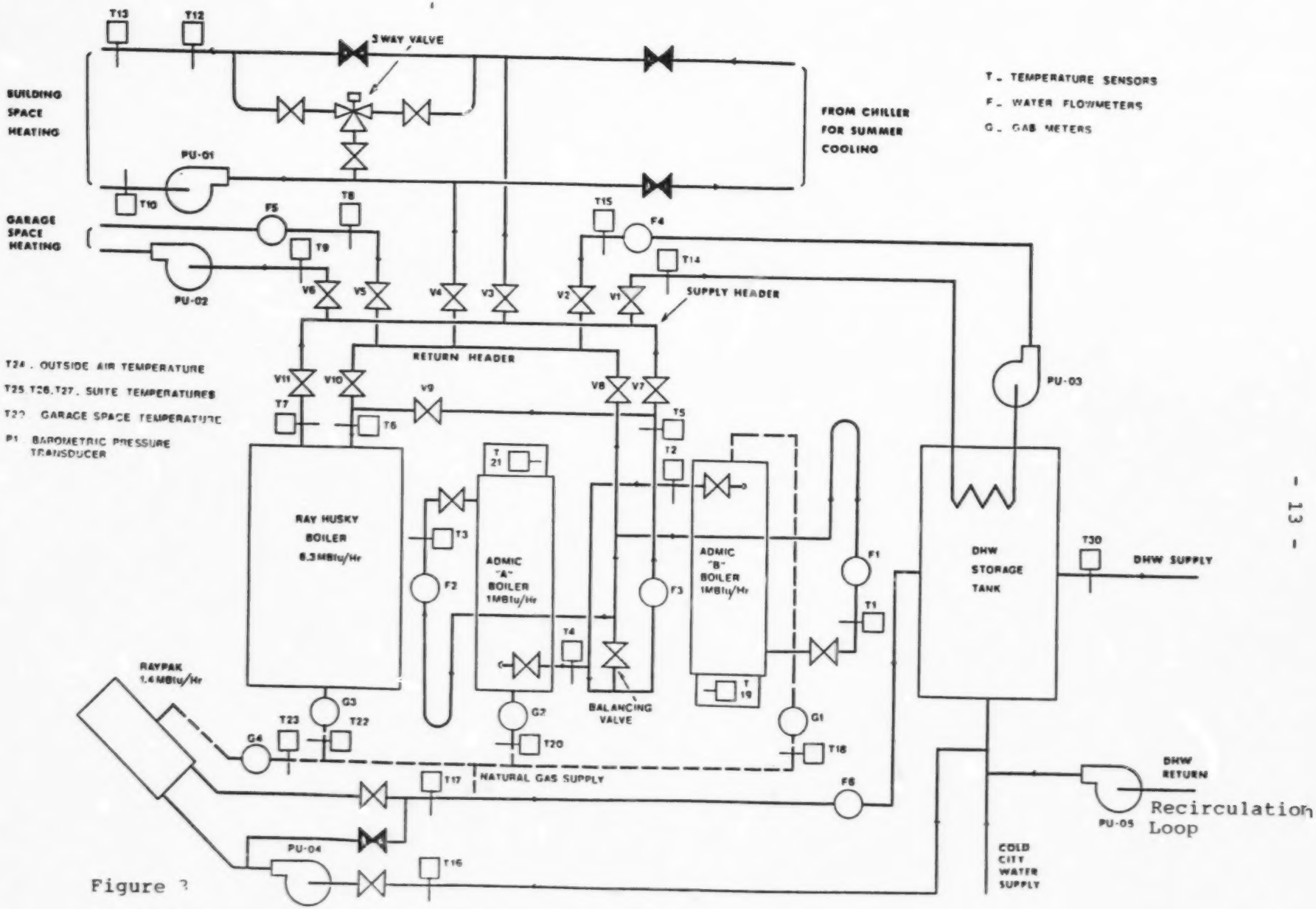

Figure 3

MONITORING EQUIPMENT LOCATION FOR 1407 ROYAL YORK SPACE AND DHW HEATING SYSTEM

TABLE 3

MONITORING EQUIPMENT SPECIFICATIONS

Monitoring Equipment		Make Model No.	Factor	Range	Accuracy
1. Temperature Sensors		ADMIC Controls		-40 to 120 C	±0.1 C at calibration point ± 1.0 C over the operating range
2. Flowmeters		Foxboro Vortex shedding meter with pulse output		(US gpm)	
No	Size				
F1	2"	E83W-02SSPT	34.984 P/US gal	12-230	±0.75%
F2	2"	E83W-02SSPT	34.286 P/US gal	12-230	±0.75%
F3	6"	E83F-06S1KSP	1.356 P/US gal	163-2060	±1.35%
F4	2"	E83W-02SSPT	34.976 P/US gal	12-230	±0.75%
F5	3"	E83W-03SSSIA	10.806 P/US gal	25-510	±0.75%
F6	1-1/2"	E83L-1HS30SP	74.156 P/US gal	7-140	±0.75%
3. Gas meters		ROMET Rotary meter with MAGNAPULSAR Pulse head		(ft^3 /hr)	
G1	1-1/2"				
G2	1-1/2"	RM-2000	1 pulse/10 ft^3	3.7 - 2000	0.05%
G4	1-1/2"	DD1			
G3	3"	RM-7000 S10	1 pulse/ft^3	4.9 - 7000	0.2%
4. Barometric Pressure Transducer		SETRA - 270		0-5 VDC 800-1100 Millibars	±0.3 Milli bars

6. DESCRIPTION OF OPERATING PERIOD

A complete description of various activities during the monitoring period is given in Appendix B. The observations related to the boiler operation are presented in this Section.

6.1 BOILER OPERATION

The ADMIC boilers commenced continuous operation on January 23, 1987 and since then have been operating satisfactorily. The number of operating hours registered by each boiler between January 23, 1987 to June 1, 1987 are as follows:

ADMIC-A Boiler = 1632 hours

ADMIC-B Boiler = 1641 hours

Some minor disruptions in boiler operation are explained as follows:

i) The ADMIC-A boiler started cycling due to a mis-aligned UV scanner which did not detect the ignition flame, causing the boiler to shut down. The boiler operation returned to normal when the scanner was aligned with the flame.

ii) The boiler room in this installation contains a refuse incinerator which causes negative pressure in the room. This negative pressure causes undesirable backdrafting which results in shut down of boilers, from time to time. As well, aerosol cans in the trash being incinerated explode releasing fluorcarbons into the air. The other potential source of chloride bearing air-borne contaminants, such as freons, is the chiller in the next room.

To eliminate the backdrafting and the possibility of ingestion of Chlorides and Flourides in the combustion air, the outside air is supplied directly to these boilers through a sealed duct. The incinerator is scheduled to be removed this summer in accordance with recent legislation prohibiting its use.

6.2 BOILER INSPECTION

A preliminary boiler inspection was conducted on March 23, 1987 followed by two detailed inspections by CGRI staff on April 15 and 23, 1987 to assess the damage caused by flooding in the boiler room on March 2, 1987 (see Appendix B, Section B.4) due to a broken fire hydrant main outside the boiler room. The major findings were as follows:

i) A considerable amount of mud and scale was observed on the combustion chamber walls.

ii) The stainless steel flue tubes had some deposits trapped between the tubes and the baffles.

iii) The flue baffles were covered with deposit on the edges facing the bottom of the tube.

The mud scale on the combustion chamber wall and the deposits on the fire tubes and flue baffles accumulated as a result of boiler room flooding. Boilers are being cleaned thoroughly from inside to restore them to their original condition.

6.3 REPLACEMENT OF VENT TERMINAL

The original corrosion resistant galvanized steel vent terminals were found unsatisfactory and were replaced by stainless steel vent terminals.

6.4 CONDENSATE CHEMICAL ANALYSIS

The condensate sample taken from the ADMIC-B boiler was analyzed by ACG Technology Ltd. The results of their chemical analysis are as follows :

pH @ 25 C	3.6
Chloride	2.5 mg/L
Iron	0.3 mg/L
Suspended solids	< 1.0 mg/L

The condensate is presently being diluted to prevent the possible damage to the sewage piping. In future, ADMIC may employ a chemical treatment apparatus to neutralize the condensate.

7. PRESENTATION OF RESULTS

The monitoring results for all four boilers at this site are presented in this section. The data for the ADMIC and Ray Husky boilers is for building space heating. The data for the Raypak boiler is for domestic hot water heating.

An extensive methodology was developed to calculate the energy output and input and to minimize error associated with efficiency calculations. The calculation procedure is as follows:

7.1 BOILER EFFICIENCY CALCULATION PROCEDURE

The boiler thermal efficiency was calculated as follows:

Efficiency = Energy output/Energy input

The energy supplied to each boiler is calculated as follows:

Energy input = Standard gas volume in cubic meters x Natural gas heating value in kilo-Joules per cubic meter

= kJ

The energy produced by each boiler is computed by using the following expression:

$$\text{Energy output} = F \times \varrho(T1) \int_{T1}^{T2} Cp(T)\,dT \qquad \text{(kJ)}$$

Where

F	- Volume of water (cubic meters)
T1	- Boiler inlet temperature (C)
T2	- Boiler outlet temperature (C)
$\varrho(T1)$	- Water density at T1 (kg per cubic meter)
Cp(T)	- Water specific heat at temperature T (kJ/kg - C)

Analytical expressions were developed for $\varrho(T1)$ and Cp (T) using 3rd and 6th order polynomial curve fits respectively to minimize errors in heat output calculations. For a $\pm$0.75% error in flow measurement and $\pm$0.01 C differential temperature error, which is typical for this site, the error associated with the energy output is about $\pm$ 1%.

The standard gas volume is calculated by correcting the measured gas volume for temperature and pressure. A precise pressure transducer with a $\pm$0.3 millibars accuracy was installed at the site to record the barometric pressure. Compensation is provided for the fixed difference between the gas pressure and the atmospheric pressure.

7.2 THERMAL PERFORMANCE OF ADMIC BOILERS

7.2.1 ADMIC-A Boiler

The thermal performance results for the ADMIC-A boiler are summarized in Table 4 for a test period from May 2, 1987 to May 8, 1987. The boiler efficiency is calculated at 86.62% for the test period as shown in Table 4.

The test period was limited primarily due to unavailability of accurate temperature sensor data for this boiler.

7.2.2 ADMIC-B Boiler

The thermal performance results for the ADMIC-B boiler summarized in Table 5 show that during the test period from April 6, 1987 to June 4, 1987, the boiler was operating at an average thermal efficiency of 85.95%.

The data availability for this boiler was continuous excepting the period from April 22, 1987 to April 26, 1987 when a current version of the data acquisition operating system (ESOS) was being installed at this site and for the period from May 6, 1987 to May 15, 1987 when the space heating for the building was supplied by the ADMIC-A boiler only.

7.3 RAY HUSKY BOILER THERMAL PERFORMANCE

The Ray Husky boiler thermal efficiency for the seven day test period from March 26, 1987 to April 3, 1987 was calculated at 64.26% as shown in Table 6. Warm weather in April did not permit running of this boiler for a longer test period. The 64.26% may be the optimum seasonal efficiency for this boiler since the present data was collected just after major repairs and overhaul work had been performed on this boiler.

TABLE 4

ADMIC - A BOILER THERMAL PERFORMANCE RESULTS

Test Period	Water Flow rate	Gas Consumption	Input Energy	Output Energy	Boiler Efficiency
DD:MM:YY hh:mm	(L/min)	(M^3)	(GJ)	(GJ)	(%)
02:05:87 00:00					
02:05:87 24:00	231	223	7.95	6.88	86.54
03:05:87 24:00	231	230	8.28	7.23	87.30
04:05:87 11:30	231	114	4.13	3.52	85.23
06:05:87 24:00	242	460	16.36	14.00	85.57
07:05:87 24:00	245	336	11.80	10.35	87.71
08:05:87 11:00	245	186	6.62	5.78	87.34
TOTAL		1,549	55.14	47.76	
Overall					86.62

TABLE 5
ADMIC-B BOILER THERMAL PERFORMANCE RESULTS

Test Period DD:MM:YY hh:mm:	Water Flow rate (L/min)	Gas Consumption (M^3)	Input Energy (GJ)	Output Energy (GJ)	Boiler Efficiency (%)
06:04:87 12:03 To 13:04:87 12:40	247.3	2084	75.626	64.73	85.60
To 22:04:87 15:15	260.7	3144	114.146	98.29	86.11
26:04:87 00:00 To 30:04:87 24:00	258.4	1342	48.46	41.5	85.64
01:05:87 24:00	250.2	378	13.58	11.7	86.16
02:05:87 24:00	223.3	362	12.89	11.2	86.89
03:05:87 24:00	222.6	358	12.89	11.2	86.89
04:05:87 12:00	225.8	181	6.57	5.6	85.24
06:05:87 24:00	232.6	706	25.10	21.6	86.05
15:05:87 17:13 To 18:05:87 24:00	120.1	199	7.27	6.32	86.93
TO 23:05:87 24:00	121.0	419	15.07	13.1	86.73
To 26:05:87 08:13	121.5	623	22.32	19.1	85.57
02:06:87 14:23 To 02:06:87 18:58	334.5	124	4.46	3.85	86.32
04:06:87 18:23 To 04:06:87 23:15	312.3	129	4.65	3.92	84.30
TOTAL		10,049	363.03	312.11	
OVERALL					85.97

TABLE 6

RAY HUSKY - BOILER THERMAL PERFORMANCE RESULTS

Test Period	Water Flow rate	Gas Consumption	Input Energy	Output Energy	Boiler Efficiency
DD:MM:YY hh:mm	(L/min)	(M)	(GJ)	(GJ)	(%)
26:03:87 16:00 To 03:04:87 14:55	2445	15.154	560.94	360.49	64.26

7.4 RAYPAK BOILER THERMAL PERFORMANCE

The thermal performance results for the Raypak boiler summarized in Table 7 show that during the one month test period from May 6, 1987 to June 6, 1987, the boiler was operating at an average thermal efficiency of 68.13%.

The data is presented on a daily basis from May 6, 1987 to May 14, 1987 to show the energy usage pattern whereas the accumulated values are presented for the remainder of the test period. The daily DHW heating load for this building (150 suites) was measured to be 7 GJ which translates into an average DHW load of 0.54 kW per suite. This compares well with the industry benchmark of 0.5 kW per suite load for DHW heating.

It can be observed from Table 7 that the boiler efficiency varies from 66% to 70%. The efficiency is highest on the weekends due to low boiler inlet water temperatures caused by high energy draw-off, as shown in Figure 4. It is suggested that some measures should be taken to prevent the occurrence of these low water temperatures, since these temperatures cause undesirable condensation in a non-condensing boiler.

7.5 BOILER EFFICIENCY COMPUTER SIMULATION RESULTS

The thermal efficiencies for the ADMIC-A and B boilers were predicted by using the CGRI computer simulation program. The input data and the simulation results are as follows:

Measured Input Data	ADMIC-A	ADMIC-B
Condensate flow rate	0.1 L/min	0.288 L/min
Gas Consumption	467 L/min	467 L/min
Boiler inlet water temperature	45.5 C	36.7 C
Stack gas temperature	87.2 C	79.6 C
Predicted Output		
Boiler thermal efficiency	88%	91%

The predicted efficiency may be higher than the actual efficiency because the condensate measurement includes an unknown amount of condensate which has drained back from the stack. Also, heat losses in the stack and casing are not transferred to the building loads.

TABLE 7

RAYPAK BOILER THERMAL PERFORMANCE RESULTS

Test Period DD:MM:YY hh:mm:	Water Flow rate (L/min)	Gas Consumption (M^3)	Input Energy (GJ)	Output Energy (GJ)	Boiler Efficiency (%)
06:05:87 00:00					
07:05:87 24:00	178.6	298	10.61	7.0	65.98
08:05:87 24:00	178.1	290	6.89	4.7	68.20
09:05:87 24:00	178.7	294	10.25	7.2	70.24
10:05:87 24:00	179.0	287	10.08	7.0	69.44
11:05:87 24:00	178.5	291	10.29	7.1	68.99
12:05:87 24:00	180.3	295	10.72	7.2	67.16
13:05:87 24:00	179.7	290	10.55	7.0	66.35
14:05:87 24:00 To 21:05:87 24:00	178.9	282	10.08	7.0	69.44
To 29:05:87 16:30	179.1	1993	70.88	47.7	67.30
To 06:06:87 24:00	178.7	2200	79.01	53.8	68.09
	178.1	2142	74.63	51.4	68.87
TOTAL		8662	303.99	207.1	
Overall					68.13

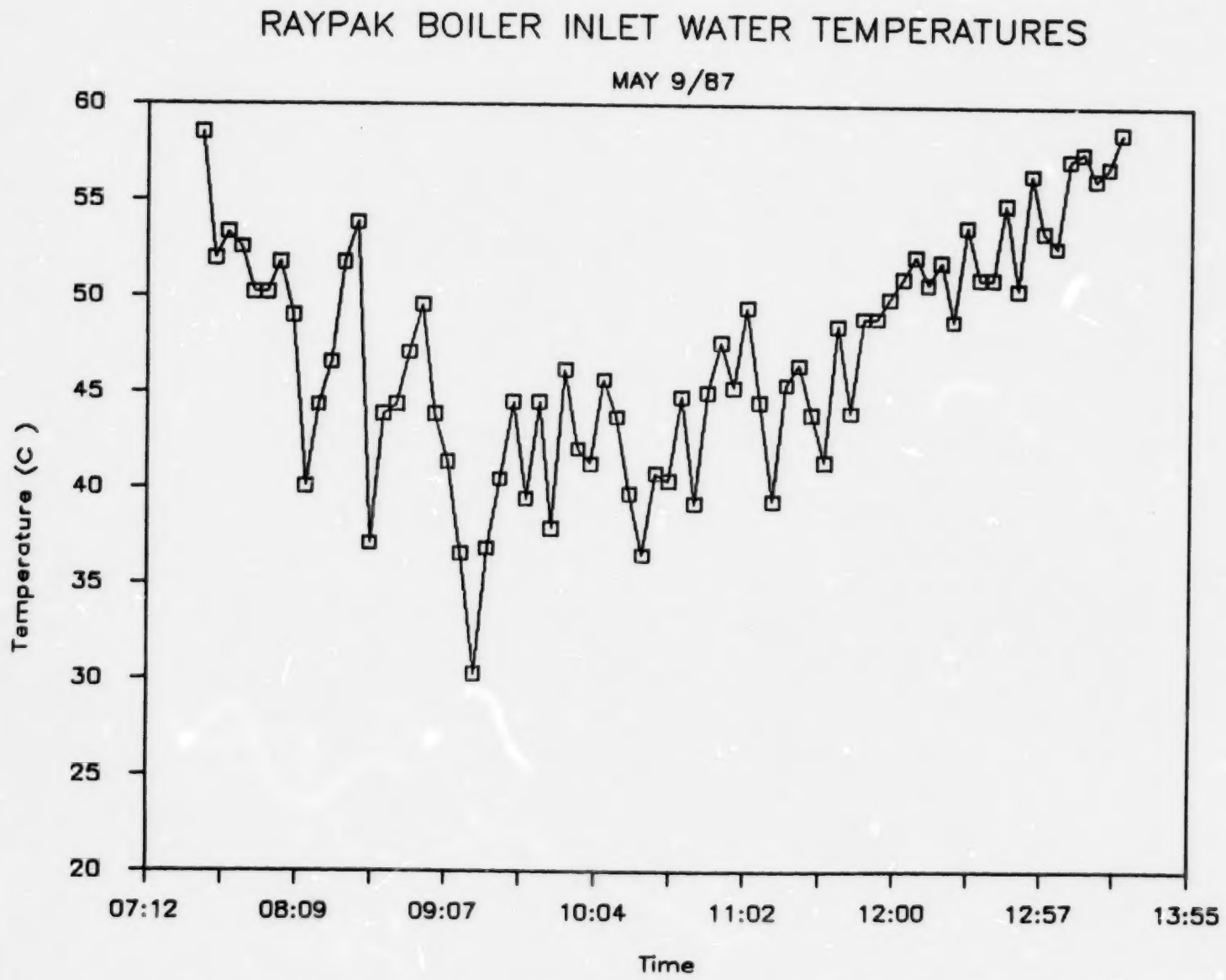

Figure 4. Raypak Boiler Inlet Water Temperatures for May 09, 1987.

8. DISCUSSION

8.1 BOILER PERFORMANCE COMPARISON

The ADMIC boiler thermal performance is compared with the performance of conventional boilers in Figure 5. The comparison shows that:

1. the ADMIC boilers with an average thermal efficiency of 86% were operating 26.5% more efficiently than the Raypak boiler;

2. the ADMIC boilers were operating 34.4% more efficiently than the Ray Husky boiler.

The high efficiency for the ADMIC boilers is achieved by:

i) recovering the latent heat from the flue gases by condensing the water vapour present in the combustion products;

ii) increasing the sensible heat recovery; the heat recovery is enhanced by the use of specially designed flue baffles;

iii) reducing stand-by losses by using spark ignition instead of a standing pilot;

iv) optimizing combustion by using a specially designed power gas burner; and

v) using a highly insulated casing.

Removal of mud scale deposits on combustion chamber and flue tube walls, caused by the flood in the boiler room, will result in higher heat transfer. Consequently, the ADMIC boiler efficiency will increase.

8.2 ENERGY SAVINGS

The total annual energy savings produced by both ADMIC high efficiency boilers are estimated at 4032 GJ per annum by comparing the ADMIC boilers efficiency (86%) with the efficiencies of the Ray Husky (64%) and the Raypak (68%) boilers. The energy saving calculations are described in Appendix C.

The space heating energy savings of 3498 GJ per annum are realized by comparing the ADMIC boiler efficiency of 86% with the Ray Husky boiler efficiency of 64%. The domestic hot water energy savings of 534 GJ are realized by comparing the ADMIC boiler efficiency of 86% with the Raypak boiler efficiency of 68%.

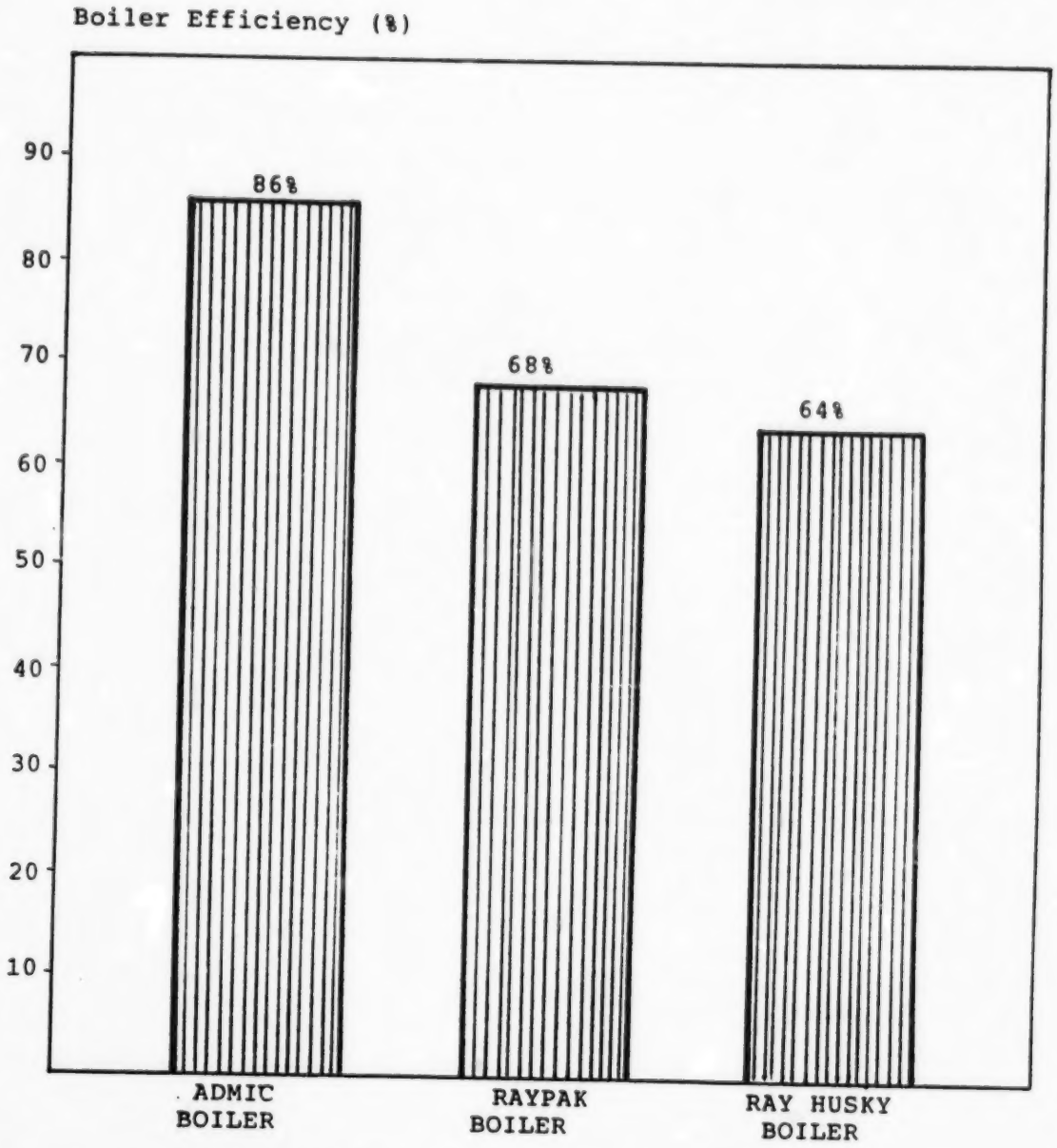

Figure 5. Comparison of High Efficiency Boiler Thermal Performance with the Performance of Conventional Boilers

8.3 COST/BENEFIT ANALYSES

The total energy savings at this site are estimated at 4032 GJ per annum which, based on a natural gas rate of $4.74 per GJ, yield a cost savings of $19,112.00 per annum.

A simple payback period of 2.25 years can be realized for a high efficiency condensing boiler by assuming that the installation costs for a high efficiency and a conventional boiler are approximately the same. The difference in their purchase price would be recovered from the energy savings produced by the high efficiency boiler. The analysis is as follows:

- Cost of one 1.055 GJ/hr (1 MBtu/hr) ADMIC high efficiency boiler including taxes = $30,000
- Cost of one conventional boiler including taxes = $10,000
- Cost to be recovered from energy savings = $20,000
- Energy savings produced by the high efficiency boiler as shown in Appendix C. = 1875 GJ per annum
- Cost savings @ $4.74/GJ natural gas rate = $8887 per annum
- Simple payback period = $\frac{\$20,000}{\$\ 8,887}$

=2.25 years

9. CONCLUSIONS

1. The monitoring results show that both ADMIC high efficiency condensing boilers were operating at an average thermal efficiency of 86%, whereas the two conventional boilers, Ray Husky and Raypak, were operating at thermal efficiencies of 64% and 68%, respectively. A comparison between these efficiencies shows that the ADMIC boilers were operating 34.4% more efficiently than the Ray Husky boiler and 26.5% more efficiently than the Raypak boiler.

2. The annual energy savings produced by the ADMIC high efficiency boilers at this site are estimated to be 4032 GJ per annum as compared to the conventional boilers. Based on a natural gas rate of $4.74 per GJ, the total yearly energy savings of 4032 GJ yield a cost saving of $19,112.00 per annum.

3. A simple payback period of 2.25 years can be realized for an ADMIC high efficiency condensing boiler by assuming that the installation cost for a high efficiency boiler and a conventional boiler would be approximately the same and that the difference in their purchase price would be recovered from energy savings produced by the high efficiency condensing boiler.

4. The ADMIC-A and B high efficiency condensing boilers registered 1632 and 1641 operating hours, respectively, during the monitoring period from January 23, 1987 to June 1, 1987 showing continuous and reliable operation.

5. The condensate pH value was measured at 3.6 suggesting that, for condensing boilers, the condensate should be diluted or chemically treated for safe disposal.

10. RECOMMENDATIONS

A. We have identified the following areas where further research and development is required:

1. The application of these high efficiency boilers for the direct heating of domestic hot water should be investigated since these boilers operate at efficiencies in excess of 90% in the condensing mode with low inlet water temperatures.

2. A stand alone electronic logic controller should be developed to optimize the boiler firing rate according to demand.

3. Newly available venting materials should be investigated for their suitability in condensing boiler applications in order to reduce costs.

4. The effects of various potentially corrosive air-borne chemicals, such as freons, containing chlorides and fluorides should be investigated.

B. As a result of our experience with the present design and installation, the following suggestions are made for the design and installation of high efficiency boilers.

1. A dedicated circulation pump for new boilers in a retrofit application should be used to reduce the requirement of large diameter piping and thereby reduce costs.

2. The outside vent stacks should be located away from the building to avoid potential complaints. Consideration should also be given to diluting the exhaust plume.

3. Where chlorides and fluorides are present in the boiler room, the outside combustion air should be supplied directly to the boilers through a sealed duct.

APPENDICES

APPENDIX A

TEMPERATURE SENSOR CALIBRATION PROCEDURE

The temperature sensors are initially calibrated in house against a laboratory standard thermometer to ± 0.1 C. With the sensor immersed in a silicone oil bath at a fixed calibration temperature, the sensor's current is set and recorded. This parameter is then used when the sensor is installed at site to ensure a proper voltage output at the calibration temperature. The calibration temperature is chosen to suit the particular application of the sensor. Since the relationship between the voltage emitted by the sensor and temperature is fixed and quite linear, temperatures can be obtained from the sensor with a high degree of accuracy.

Temperature sensor pairs are then further adjusted in order to track each other. This procedure reduces any error in the temperature difference of the two sensors which can result due to slightly different transistor properties of the sensors. Assuming that each temperature sensor obeys a linear relationship between voltage and temperature, a temperature correction factor (dT(T)) which is linear with temperature can be calculated and added to one of the temperature sensor readings to offset the error. This is done by simultaneously immersing the two sensors in a cold oil bath noting the difference in the sensor readings (dTl). The sensors are then immersed in a hot oil bath again noting the difference in the sensor readings (dTh). It should be noted that dTl and dTh are averaged over many readings (in practice around 100) to obtain a precise reading eliminating as much as possible any noise and quantization error effects. Thus, referring to the adjusted temperature as Tl and the reference temperature as T2, then

$$dTh = T2h - T1h$$
$$\text{and } dTl = T2l - T1l$$

Therefore, applying the correction factor to Tl, we obtain

$$T1h' = T1h + dTh$$
$$\text{and } T1l' = T1l + dTl$$

or more generally,

$$T1'(T) = T1(T) + dT(T)$$

The linear relationship dT(T) can then be obtained:

$$\text{slope} = (dTh - dTl)/(Th - Tl) = a$$
$$\text{ordinate-intercept} = ((dTl \times Th) - (Tl \times dTh))/(Th - Tl) = b$$

$$\text{and } dT(T) = a \times T + b$$

This relationship is then incorporated into the temperature sensor Tl's conversion formula.

APPENDIX B

BOILER COMMISSIONING AND SITE ACTIVITIES

B.1 BOILER COMMISSIONING

The ADMIC boilers started continuous operation on January 23, 1987 and since then have been operating satisfactorily without any major problem. Some minor problems during commissioning caused small disruptions in boiler operation which are explained as follows:

i) The gas meter rotating element for the ADMIC-A boiler was jamming due to dust particles, probably trapped inside the gas line during installation. This was corrected by manually rotating the element until the movement was free.

ii) The ADMIC-A boiler started cycling due to a mis-aligned scanner which would not detect the ignition flame, causing the boiler to shut down. The boiler operation was normal when the scanner was aligned with the flame.

B.2 THREE-WAY VALVE MOTOR REPLACEMENT

The 50 lb-in torque Modutrol motor supplied with the valve was found to be undersized and was replaced by a bigger 150 lb-in torque motor. The original motor would close the valve only to the half position due to small torque. The new motor was able to modulate the valve through its entire range.

B.3 EXTENSION OF OUTSIDE VENT PIPE

The outside vent pipe was extended by 20 feet to keep the exhaust plume away from the building. Originally the vent stacks were 25 feet from the building.

B.4 BOILER ROOM FLOODING

The boiler room was flooded to a depth of three feet of water on March 2, 1987 as a result of a broken outside fire hydrant pipe. The two ADMIC boilers and their gas controls were submerged under water for about six hours. Both boilers, which kept running under water until they were turned off manually, started without any problem when the water was pumped out. This shows confidence in reliable operation of these boilers under adverse conditions. The gas valve micro-switch on ADMIC-A boiler short-circuited temporarily but worked normally when the moisture dried out.

B.5 SLIDING OF BAFFLES TOWARDS THE END PLATE

An inspection showed that the baffles in both boilers had slid out of their places by 6" to 12" towards the collector hood end plate. Since the boilers are sloped towards the collector hood to ensure proper drainage of condensate, any vibrations resulting from boiler start-up and shut-down operations would have caused this sliding of baffles. These baffles were cleaned and repositioned.

B.6 REPLACEMENT OF FLOWMETERS

The 2" flowmeter (F5) in the garage loop and 1 1/2" flowmeter (F4) in the domestic hot water loop from the main header were replaced by larger size meters of 3" and 2" respectively to reduce the pressure drop through those loops.

B.7 GAS METER IMPULSE HEAD

The impulse head on the gas meter (G3) for the Ray Husky boiler was initially producing erratic pulses. The impulse head was repaired by the manufacturer's service person prior to collection of data.

B.8 SIX INCH VORTEX FLOW METER

The 6" vortex flowmeter was pulsing too quickly. The jumper inside the impulse head, set at 10X cap multiplier, was removed to 1X cap multiplier to obtain the correct flow measurements prior to collection of data.

B.9 TEMPERATURE SENSOR CALIBRATION

Temperature sensor pairs were calibrated at site using hot and cold oil baths to ensure that the temperature sensors were tracking each other. During this calibration and installation, the temperature sensors were damaged producing erronous data, especially for the ADMIC-A boiler, resulting in loss of data.

B.10 RAY HUSKY BOILER REFURBISHING

Major work was done on this boiler to repair a tube leak. The boiler controls were also totally replaced following the March 2, 1987 boiler room flood.

B.11 ADMIC BOILERS INSULATION

Both ADMIC boilers were insulated by two inch thick fiberglass insulation with canvass jacketing on April 10, 1987.

APPENDIX C

ENERGY SAVINGS CALCULATIONS

C.1 YEARLY ENERGY SAVINGS FROM THE TWO ADMIC BOILERS

The total yearly energy savings produced by the two ADMIC boilers at this site for the combined space and domestic hot water heating are based on the following measured thermal efficiencies.

ADMIC Boiler = 86%

Ray Husky Boiler = 64%

Raypak Boiler = 68%

Space Heating Energy Savings

The space heating energy savings are calculated by comparing the ADMIC boiler and the Ray Husky boiler efficiencies.

Energy consumption for the ADMIC boiler = 1.055 GJ/hr

Energy output from the ADMIC boiler = 0.907 GJ/hr

Energy consumption for the Ray Husky boiler to produce 0.907 GJ/hr = 1.417 GJ/hr

Energy savings = 1.417 - 1.055

= 0.362 GJ/hr

Energy savings per boiler per heating season = 0.362 x (4 months x 100% +
2 months x 80% +
2 months x 50%)
730 hours/month

= 1744 GJ per annuam

Energy savings from two ADMIC boilers = 1744 x 2

= 3488 GJ

Domestic Hot Water Energy Savings

The domestic hot water energy savings are calculated by comparing the ADMIC boiler performance with the Raypak boiler since the Raypak boiler provides domestic hot water heating at this site.

DHW Load = 7 GJ/day x 30.4 days/month

= 212.8 GJ/month

Gas consumption for the Raypak Boiler = 212.8/0.68

= 312.9 GJ/month

Gas consumption for the ADMIC boiler = 212.8/0.86

= 247.4 GJ/month

Energy savings = 312.9 - 247.4

= 65.5 GJ/month

Energy savings from the ADMIC boiler for 8 months, since for the remaining 4 months 100% of the ADMIC boiler capacity was used for space heating = 65.5 GJ/month x 8 months

= 524 GJ

Total yearly energy savings from combined space and domestic hot water heating = 3488 + 524

= 4012 GJ

C.2 ENERGY SAVINGS TO EVALUATE PAYBACK PERIOD

Efficiency of an ADMIC boiler = 86%

Efficiency of a conventional boiler = 68%

Energy input for an ADMIC boiler = 1.055 GJ/hr

Energy input for a conventional boiler to produce energy equivalent to ADMIC boiler = 1.334 GJ/hr

Energy savings = 1.334 - 1.055

= 0.28 GJ/hr

= 21%

Space heating energy savings	= 0.28 GJ/hr x (4 month x 100% + 2 month x 80% + 2 month x 50%) x 730 hrs/month
	= 1349 GJ per annum
Domestic hot water energy savings	= 7 GJ/day x 30.4 days/month x 8 months x 1/0.68 x 0.21
	= 526 GJ per annum
Total Energy Savings	= 1875 GJ per annum